Electron Identification

Background Rejection

Detector Parameters and Geometry

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Fermilab and CERN

Argonne Off-axis detector Workshop
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OUTLINE

I Event Generation

- F Beam issues.
- F Detector set-up

II Useful Variables

III Sampling Frequency

IV 2D vs 1D

V Event Numbers

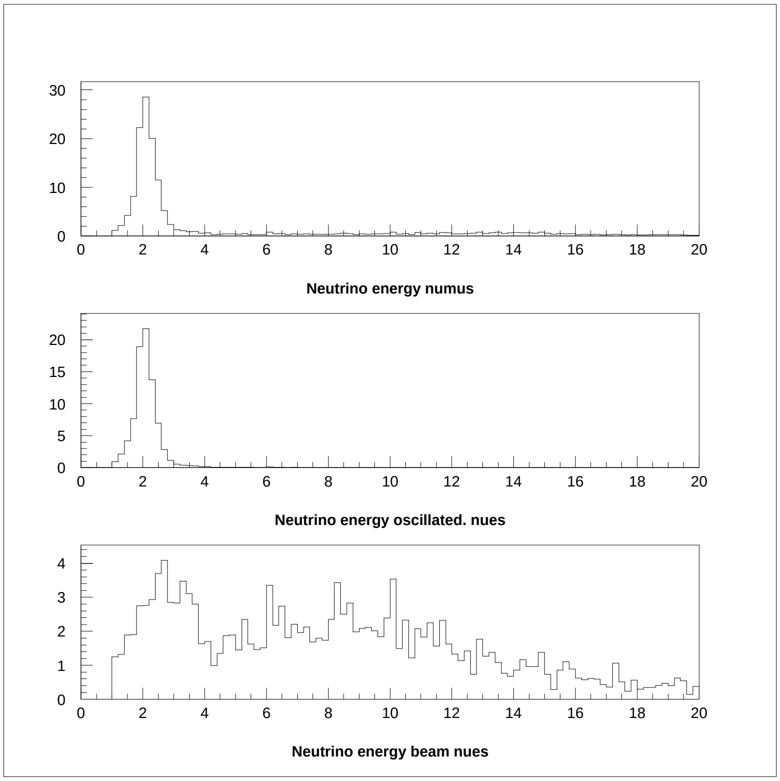
VI Strategy for Background Estimates

VI CP violation?

Work of many people at Stanford and Fermilab.

EVENT GENERATION:BEAM ISSUES

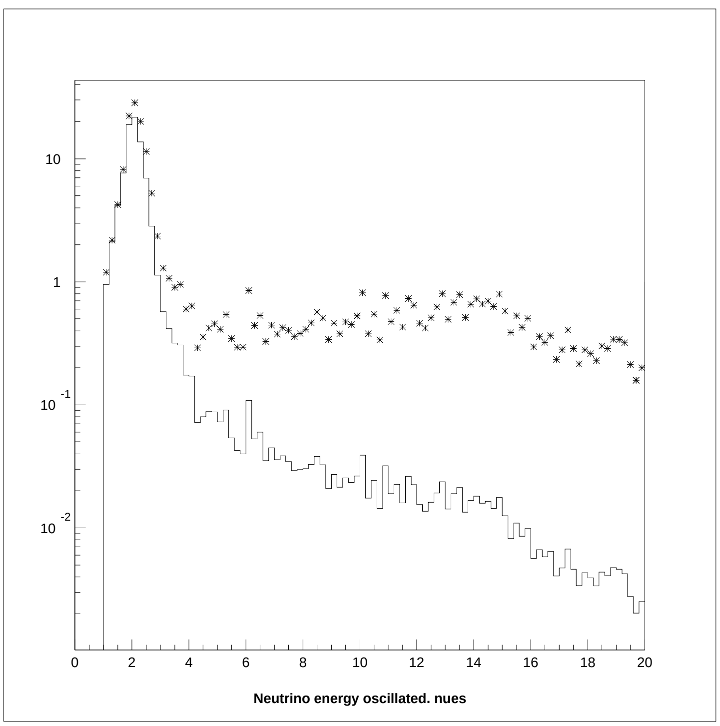
732 km 10km Off-Axis 14mrad



Beam ν_μ

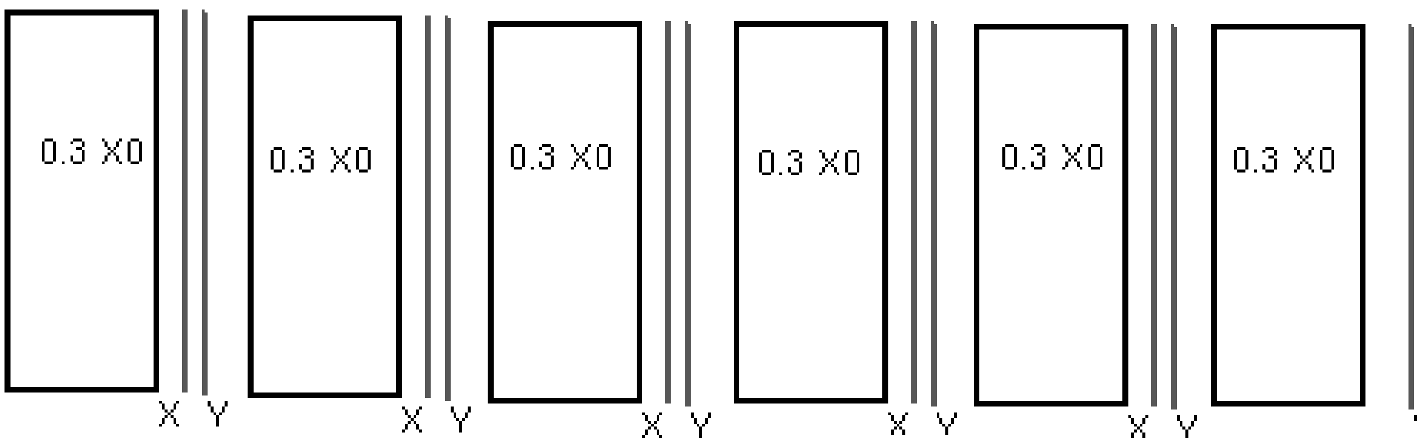
Oscillated ν_e

Beam ν_e



EVENT GENERATION:DETECTOR SET UP

- $0.3\ X_o \sim$ 17.5 cm Absorber Density $0.71\ gm.cm^{-3}$.
  - 5 cm air
  - 12.5 cm plastic
- Plane of horizontal (X) strips. 3 cm wide.
- Plane of vertical (Y) strips. 3 cm wide.



BY IGNORING SUITABLE DETECTOR PLANES
THIS ALLOWED STUDIES OF

- Increasing the absorber thickness.
- Alternating X and Y read out.

EVENTS GENERATED WITH FLAT SPECTRA:

- 2000 ν_e events. 1 to 3 GeV.
- 2000 ν_e events. 3 to 20 GeV.
- 10000 ν_μ events. 1 to 3 GeV
- 10000 ν_μ events. 3 to 20 GeV

THEN REWEIGHTED TO APPROPRIATE BEAM SPECTRA.

BACKGROUND AND DEFINITION OF VARIABLES

FOUR types of background

- Beam ν_eCC events.
- ν_μ NC events.
- ν_μ CC events with a missed μ.
- Oscillated ν_τ CC events with the τ decaying to an electron or to hadron(s).

The following studies were made by

- Reconstructing tracks in the events.
- Studying the track with the Largest number of hits.
- Examining Global Event characteristics.

TRACK RECONSTRUCTION

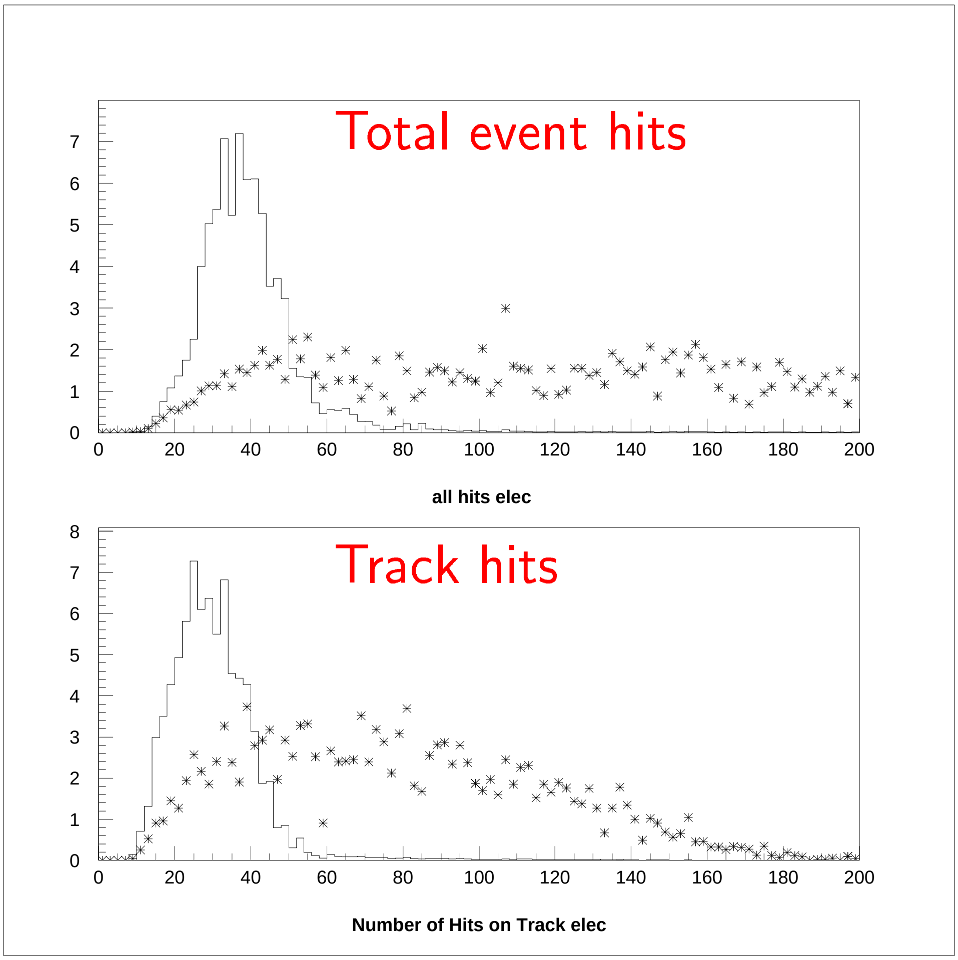
For EACH VIEW

- HOUGH transform.
  - Generate all possible straight lines in 100 SLOPE and 100 INTERCEPT bins.
  - For each slope and intercept find how many hits are within a tolerance.
  - Find which line, LINMAX (SLOPE and INTERCEPT) includes the most hits.
- Find all the hits that are within 15cm of the LINMAX line.
- Fit a straight line to these hits.
- Iterate 3 more times, finding the hits and refitting.
- Fit a quadratic to the hits included in the last iteration.
- Associate to the track all hits within 15cm of the quadratic.

BACKGROUND FROM BEAM ν_e

Their distinguishing characteristics will be:

- Their high energy. $\Rightarrow$ Large number of hits in event.
- The high energy of their electron. $\Rightarrow$ Large number of hits on the electron track.

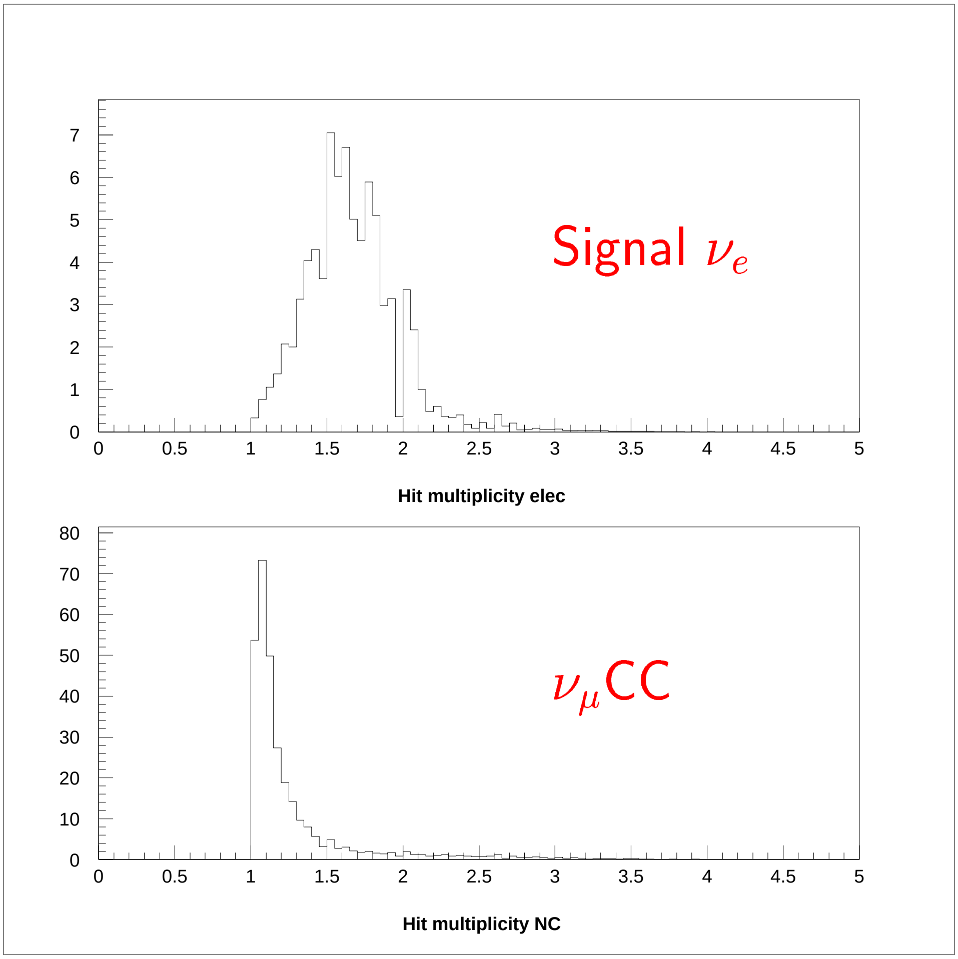


MUST CUT HARD ON TOTAL NUMBER OF HITS IN EVENT.

BACKGROUND FROM ν_μCC

Their distinguishing characteristic will be:
The number of hits/plane associated to the track
MULTIPLICITY.

- F ELECTRONS from ν_eCC shower.
  $\downarrow$
  MORE than one hit per plane: MULTIPLICITY > 1.
- F MUONS from ν_μCC do not shower.
  $\downarrow$
  MULTIPLICITY ~ 1.



MUST ALSO CUT HARD ON MULTIPLICITY.

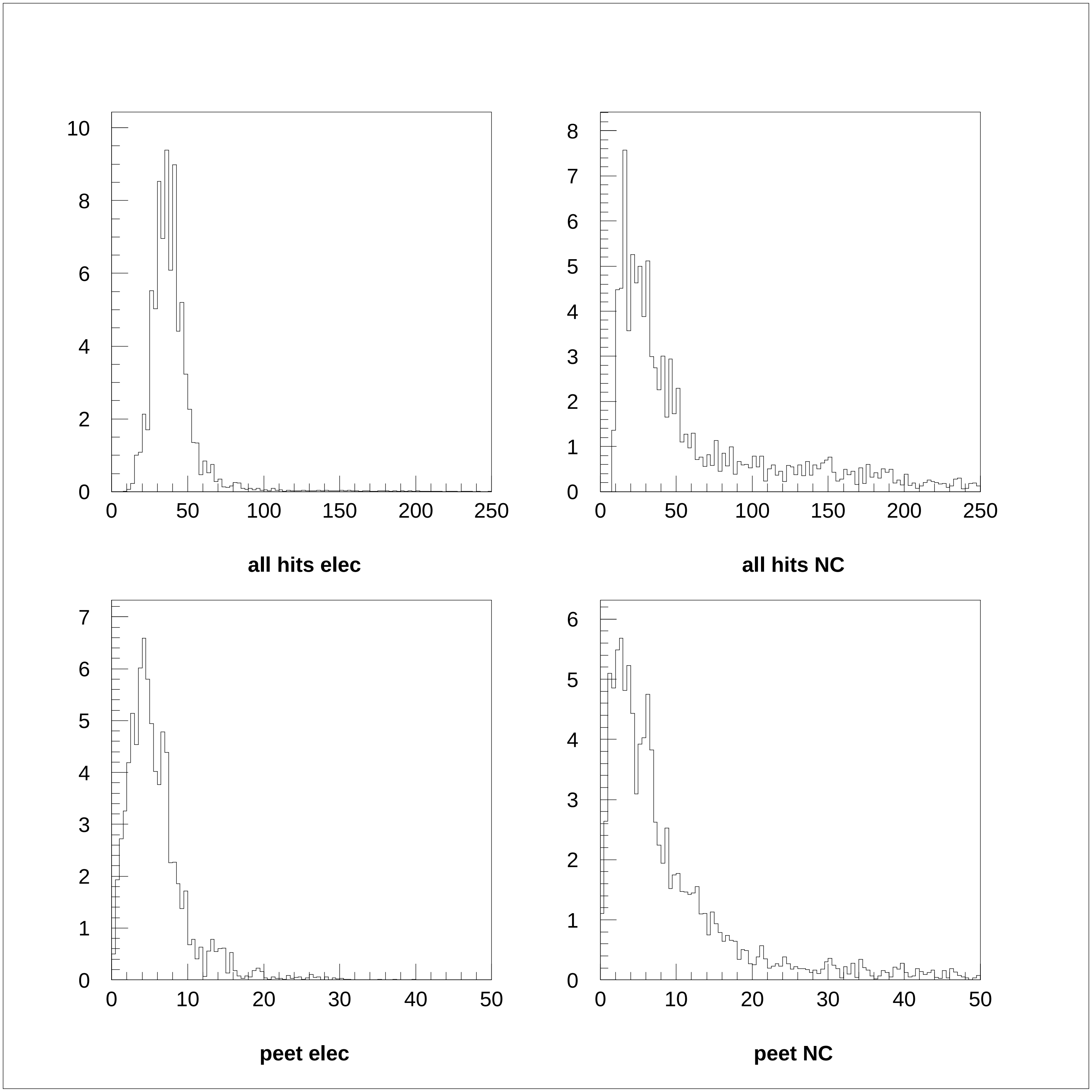
STRATEGY

- F Apply loose cuts to reject OBVIOUS Neutral Currents.
- F Tight cut on TOTAL HITS in event to reject Beam ν_e.
- F Tight cut on MULTIPLICITY in event to reject ν_μCC.
- F Construct several Probability density functions for Signal ν_e and NC.
- F Combine these to calculate likelihoods for each event to be a Signal ν_e, L^{sig} or a NC L^{NC}.
- F Take the log of the ratio of these likelihoods.

$$\mathrm{R} = \log(\frac{\mathrm{L^{sig}}}{\mathrm{L^{NC}}})$$

- F Cut on R such as to make the NC background SMALLER than the BEAM ν_e background:O(10 events).

LOOSE CUTS I



10
8
6
4
2
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50
100
150
200
250
all hits elec
8
7
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all hits NC
7
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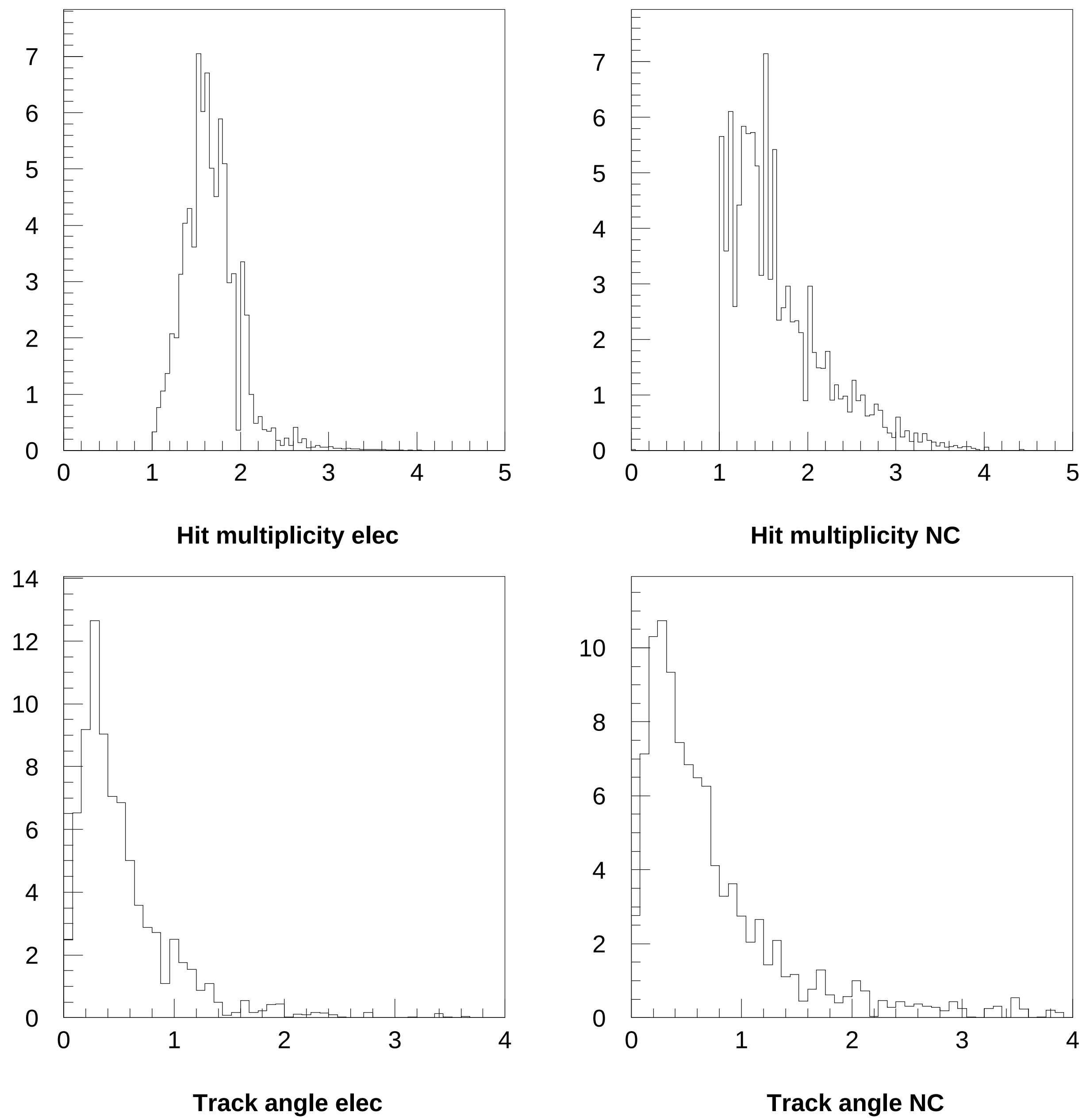
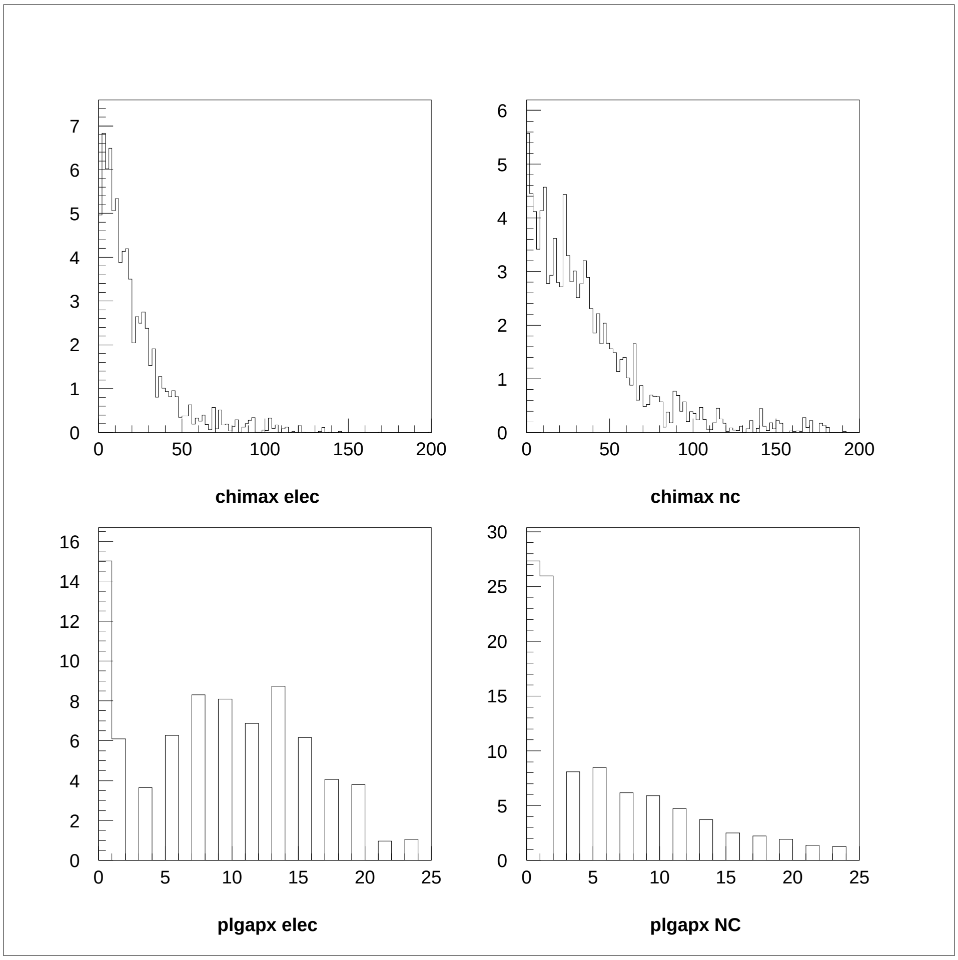
peet NC

LOOSE CUTS II



LOOSE CUTS III

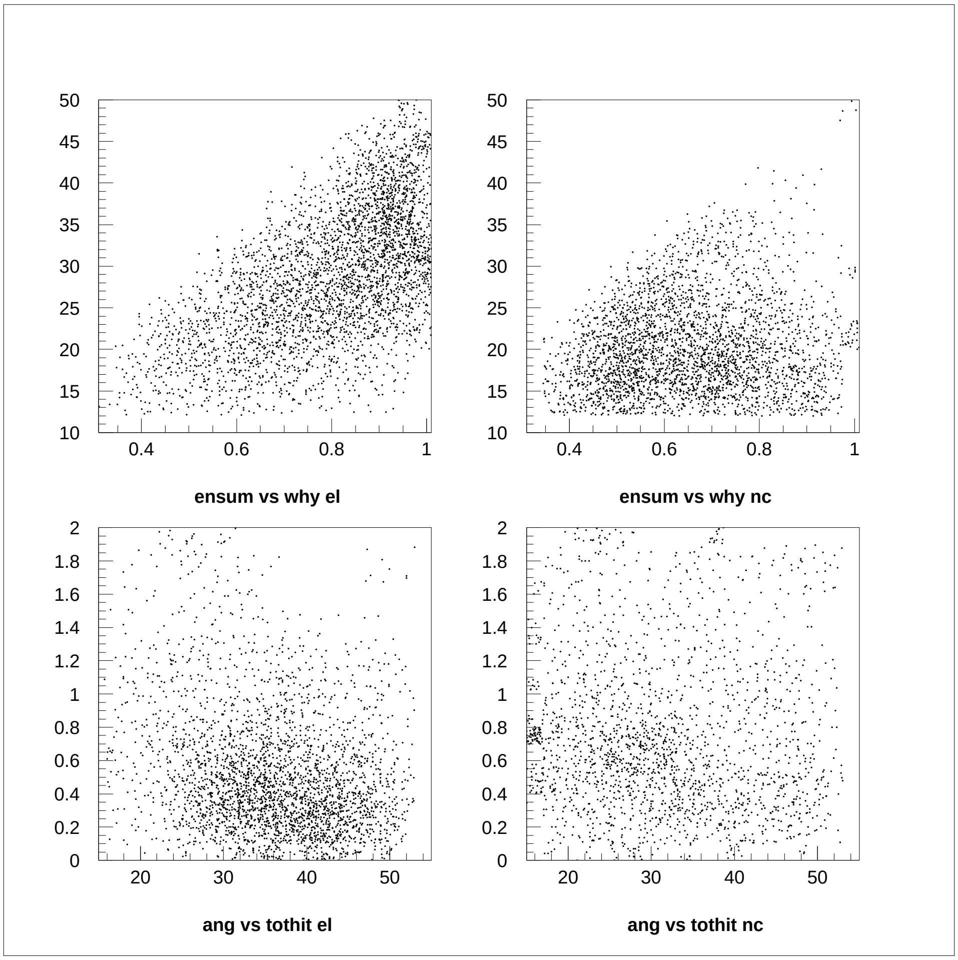


LOOSE CUTS

Sampling	0.3 X_0	0.6 X_0
Total hits	$32 \leq$ Tot ≤ 100	$16 \leq$ Tot ≤ 50
Track hits	$24 \leq$ Tot ≤ 100	$12 \leq$ Tot ≤ 50
P_T	$\leq 40.$	$\leq 20.$
χ^2	$\leq 100.$	$\leq 100.$
Track hits/plane	$1.3 \leq$ Mult ≤ 3.0	$1.3 \leq$ Mult ≤ 3.0
Gap plane	$\neq 1$	$\neq 1$

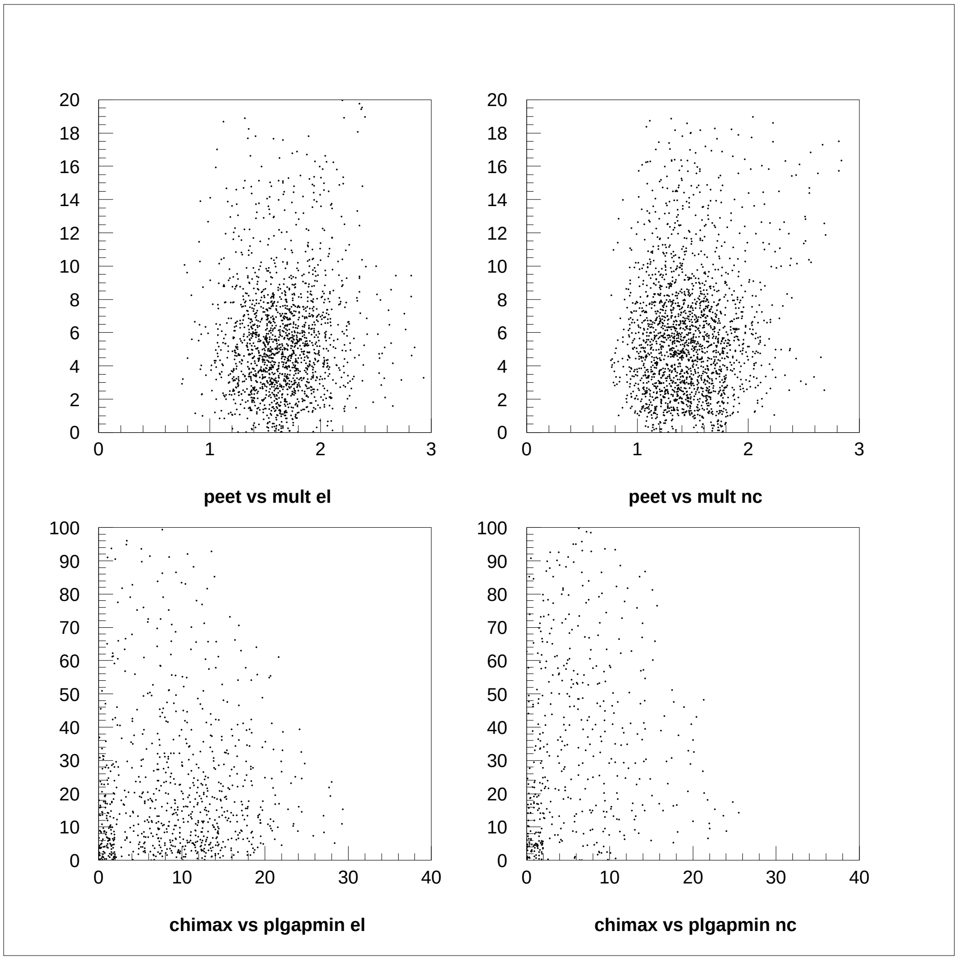
Particle Density Functions I

- F FOUR 2-D histograms of relevant variables for NC events and same plots for Signal events.
- F Smoothed.
- F $P_1^s, P_2^s, P_3^s, P_4^s$ for the signal.
- F $P_1^b, P_2^b, P_3^b, P_4^b$ for the background.



- F Num. Track hits vs Fraction of Event hits associated to track. P(ntr,y).
- F Angle of track to beam vs Total Num. Event hits. P(ang,nto).

Particle Density Functions II



- P_T vs Multiplicity. P(pt,mul).
- χ^2 vs Plane of first gap on track.P(chi,pl).

LIKELIHOODS

For each event compute:

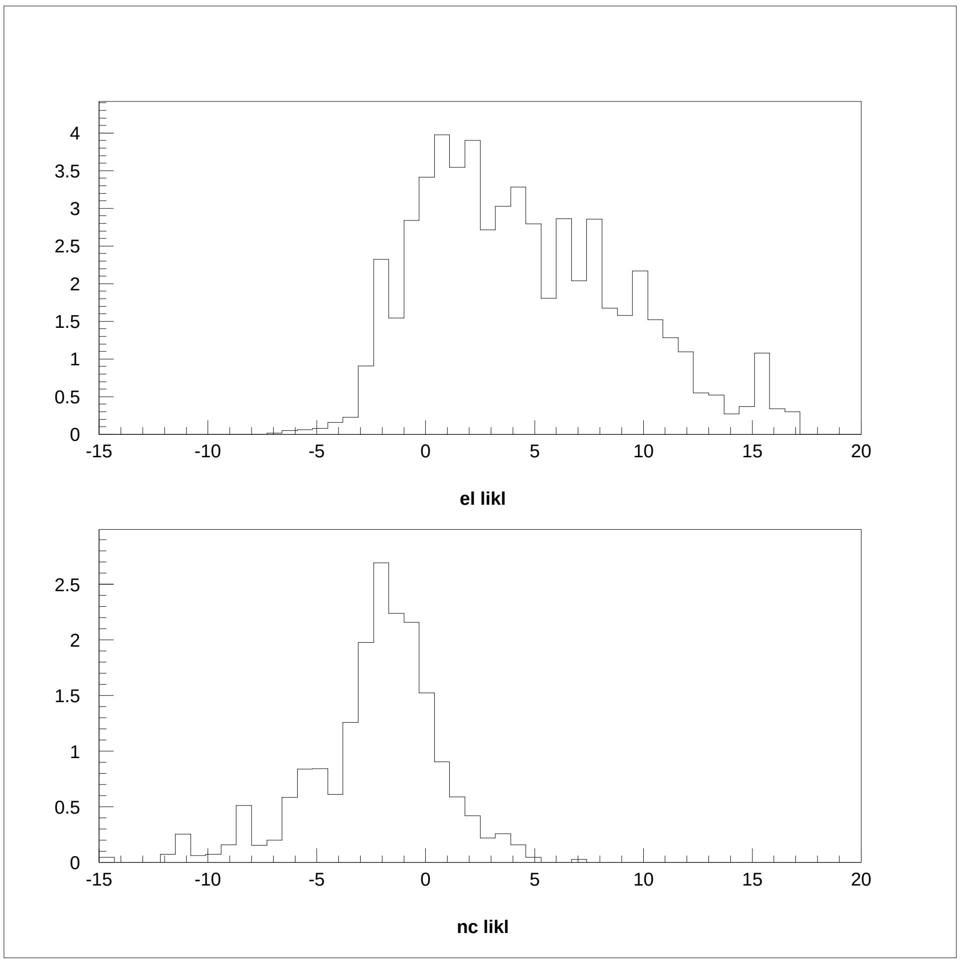
$$L^{sig} = P^{s}(ntr, y) \times P^{s}(ang, nto) \times P^{s}(pt, mul) \times P^{s}(chi, pl)$$

$$L^{sig} = P^{NC}(ntr, y) \times P^{NC}(ang, nto) \times P^{NC}(pt, mul) \times P^{NC}(chi, pl)$$

and

$$R = \log(\frac{L^{sig}}{L^{NC}})$$

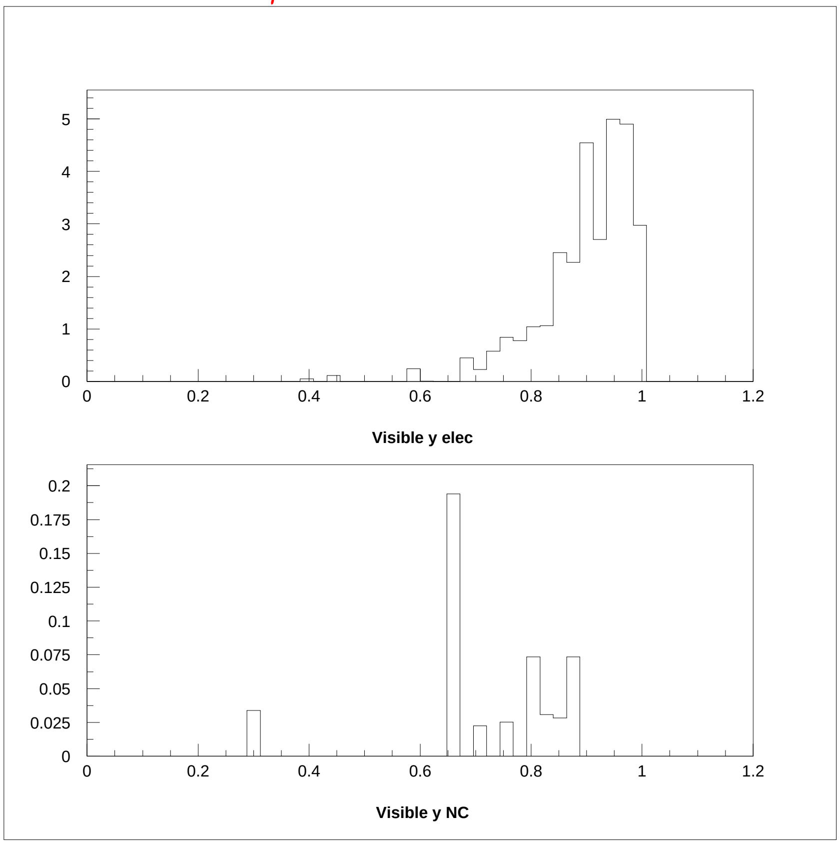
0.6 X_0 Example

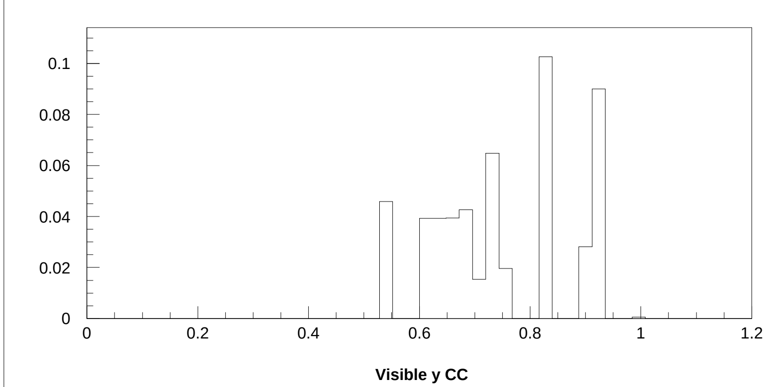


Cut at R $>$ 3.5

AN ADDITIONAL CUT

Also ran the ν_μCC events through the same analysis.





Most of the background in BOTH NC and CC events is at LOW y (the fraction of the event hits associated to electron.

Also Reject events at $y < 0.7$

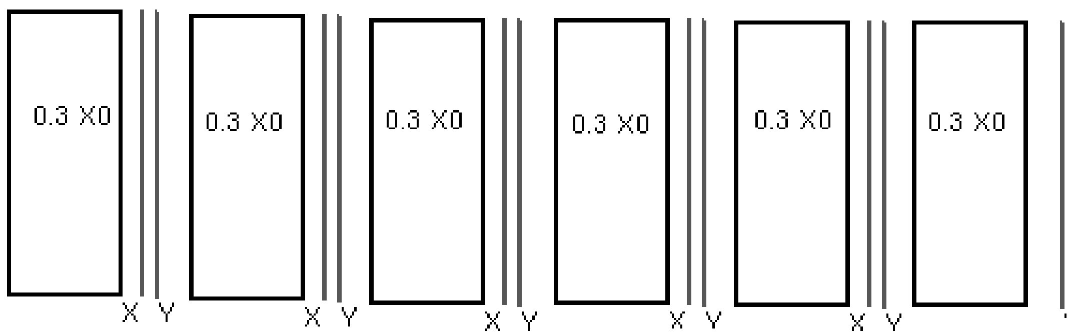
INPUT

- Signal:
  - $\sin^2 2\theta_{13} = 0.1$
  - $\Delta m^2 = 2.4 \times 10^{-3}$
- Signal Efficiency: Survivors after cuts divided by FULL oscillated spectrum.
- Location: 735 km 10km off-axis.
- Detector: 50 ktons. 42.5 ktons after fiducial cut.
- Running time: 5 years at 4.0 x 10^{+20} pots/year.
- Beam
  - ν_μ 114.7 CC events per kton.year.
  - ν_e 2.5 CC events per kton.year.
- Figure of Merit

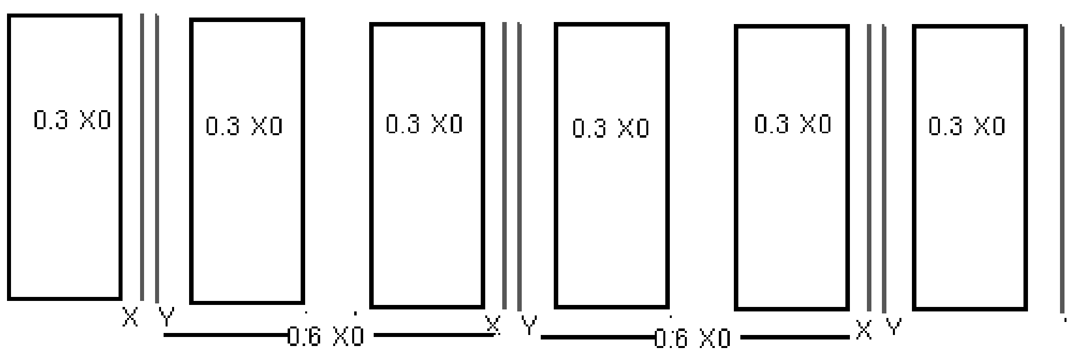
$$\mathrm{FOM} = \frac{\text{Number of Signal Events}}{\sqrt{\text{Total Number of Background Events}}}$$

SAMPLING FREQUENCY RESULTS

0.3 X_0 X and Y



0.6 X_0 X and Y



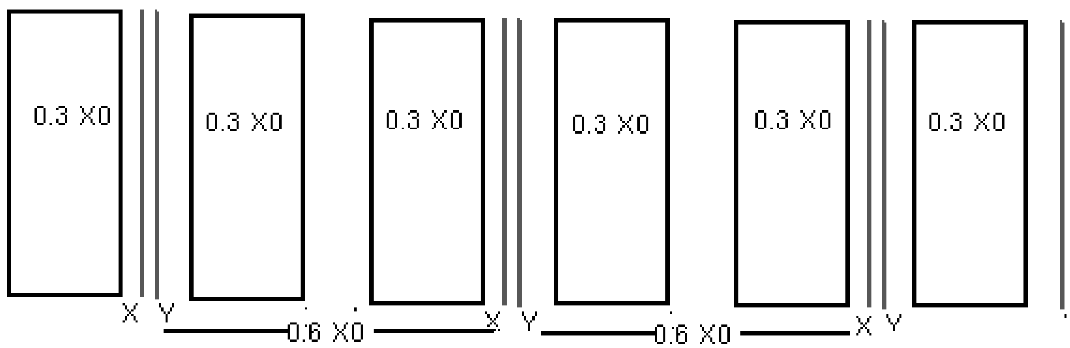
50 ktons, 5 years, 4 x 10^{20} pot/yr, 85% Fid. volume

	0.3 X_0 X and Y	0.6 X_0 X and Y
NC efficiency	1.26 x 10^{-3}	1.16 x 10^{-3}
ν_μ NC background	14.5	13.3
CC efficiency	3.56 x 10^{-4}	4.38 x 10^{-4}
ν_μ CC background	8.8	10.8
Beam ν_e efficiency	0.068	0.059
Beam ν_e background	36.3	31.3
Total background	59.6	55.4
Signal efficiency	0.424	0.349
Signal events	295.0	243.5
Figure of Merit	38	33

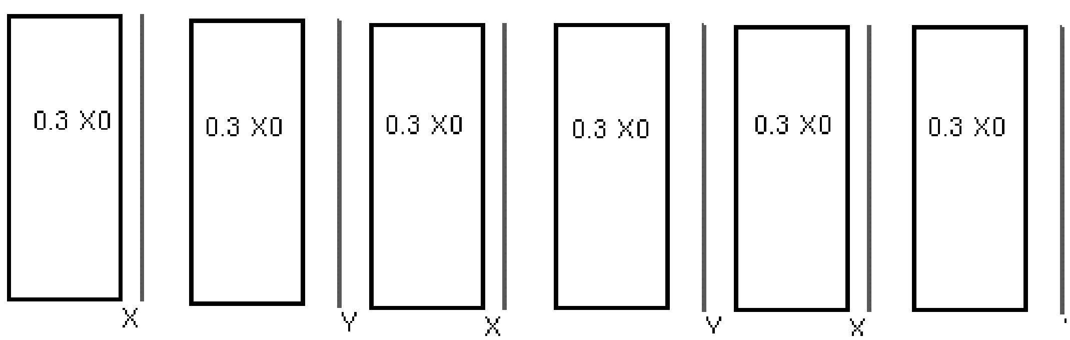
Thin absorber: 16% better Figure of Merit

X and Y vs X or Y: Given NUMBER of active planes.

0.6 X_0 X and Y



0.3 X_0 X or Y



50 ktons, 5 years, 4 x 10^{20} pot/yr, 85% Fid. volume

	0.3 X_0 X or Y	0.6 X_0 X and Y
NC efficiency	8.4 x 10^{-4}	1.16 x 10^{-3}
ν_μ NC background	9.5	13.3
CC efficiency	4.10 x 10^{-4}	4.38 x 10^{-4}
ν_μ CC background	10.0	10.8
Beam ν_e efficiency	0.058	0.059
Beam ν_e background	31.0	31.3
Total background	50.5	55.4
Signal efficiency	0.335	0.349
Signal events	233.5	243.5
Figure of Merit	33	33

No difference

STAN'S ANALYSIS

- For a given number of active planes: 0.3 X_0 X or Y and 0.6 X_0 X and Y.
- Sampling Frequency 0.3 X_0 and 0.6 X_0.
- Gaussian beam centred at 2 GeV and half width 0.4 GeV for signal and background.
- Sequential cuts.

	0.3 X_0 X or Y	0.6 X_0 X and Y	0.3 X_0 X and Y
ν_μ NC background	5.6	6.3	16.0
ν_μ CC background	7.7	7.3	6.3
Beam ν_e background	15.0	15.7	22.3
Total background	28.3	29.3	44.6
Signal efficiency	0.317	0.322	0.466
Signal events	169.7	171.9	249.2
Figure of Merit	32	32	37

CONCLUSIONS

- Sampling Frequency: Thinner aborber improves FOM by 16%.
- X and Y vs X or Y: For a given number of planes: No Difference

Fermilab-Stanford Comparison

Stanford analysis with:

- Realistic ν_e and ν_μ beams.
- Thin segmentation.
- $\Delta m^2 = 2.8 \times 10^{-3}$

	Fermilab	Stanford
NC efficiency	1.26×10^{-3}	3.9×10^{-3}
ν_μ NC background	14.5	31.0
CC efficiency	3.56×10^{-4}	6.4×10^{-4}
ν_μ CC background	8.8	15.0
Beam ν_e efficiency	0.068	0.048
Beam ν_e background	36.3	24.0
Total background	59.6	70.0
Signal efficiency	0.42	0.41
Signal events	295	323
Figure of Merit	38	39

Very Compatible

CONCLUSIONS ON GEOMETRY

Running with a THICKER sampling
only worsens the FOM by 16%,
which is still acceptable.

To use a THICKER absorber and recover the 16%:

- Run longer → Higher Running costs.

- Increase overall detector mass by 30%.
  → More absorber and building costs
  to be compared to savings on half the active detector costs

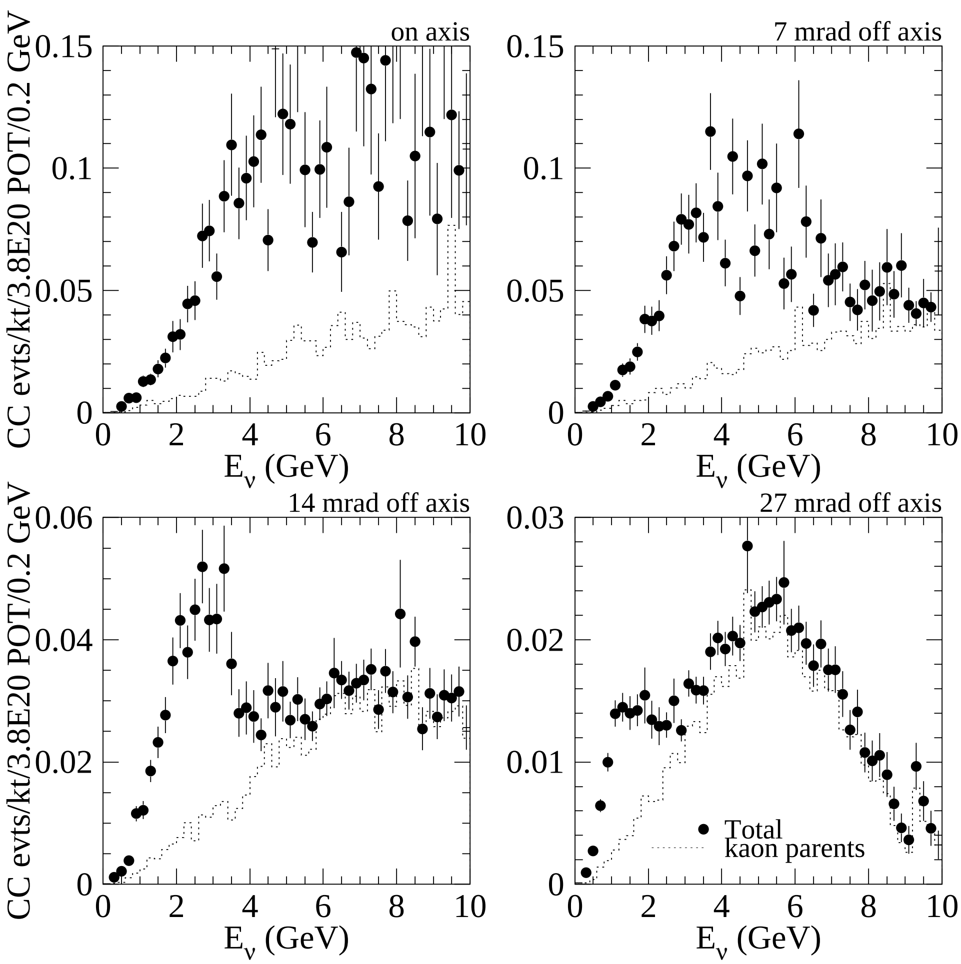
- If RPC's are used, install them every 0.3 X_0
  but only instrument alternate X and Y strip planes.
  Install missing electronics when more funds become available.
  → Only possible if electronics are NOT buried within detector

BACKGROUND EVALUATION

As much as possible base background estimates on the DATA themselves.

Beam ν_e

- Measure in NEAR detector.
- Validate Monte Carlo Beam prediction.
- Use Monte Carlo to extrapolate to FAR detector.
- Validate extrapolation in HIGH Energy region where no oscillated signal is expected.
  BUT different origin
  of LOW energy ν_e μ decay,
  and of HIGH energy ν_e K decay.



BACKGROUND EVALUATION II

ν_μCC

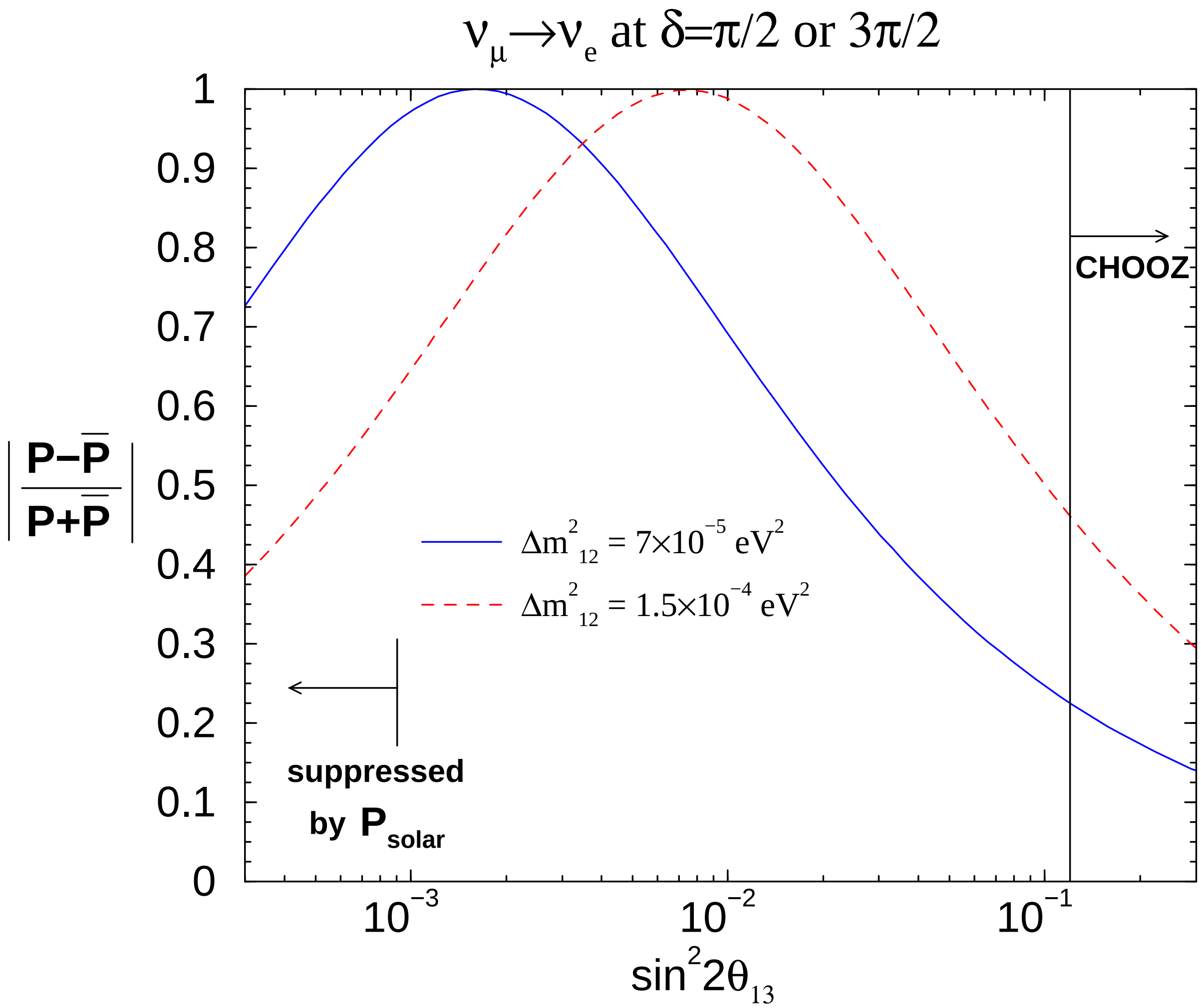
- Measure RECOGNIZED ν_μCC in NEAR detector
- Validate Monte Carlo Beam prediction.
  Important for 2 reasons.
- 1st Reason:ν_μCC Background evaluation.
  - Extrapolate to FAR detector.
  - Apply SURVIVAL probability.
  - Validate Monte Carlo extrapolation with RECOGNIZED ν_μCC in FAR detector.
  - Use validated Monte Carlo to compute SMALL number of UNRECOGNIZED ν_μCC background.
- 2nd Reason:Needed for Neutral current background estimates.

ν_μNC

- The ν_μNC measured in the NEAR detector will be a MIXTURE of
  real ν_μNC and UNRECOGNIZED ν_μCC events.
  This mixture will be DIFFERENT in the NEAR and FAR detectors because of Oscillations.
- From the measured number of ν_μCC events in NEAR detector, compute, using the Monte Carlo, the SMALL number of UNRECOGNIZED ν_μCC events.
- From these calculate the REAL number of ν_μNC.
- Extrapolate to FAR detector.
- EXTRA CHECK: Use reconstructed ν_μCC as a Neutral Current simulator: Ignore the Muon.

CP violation

Calculation by Stephen Parke

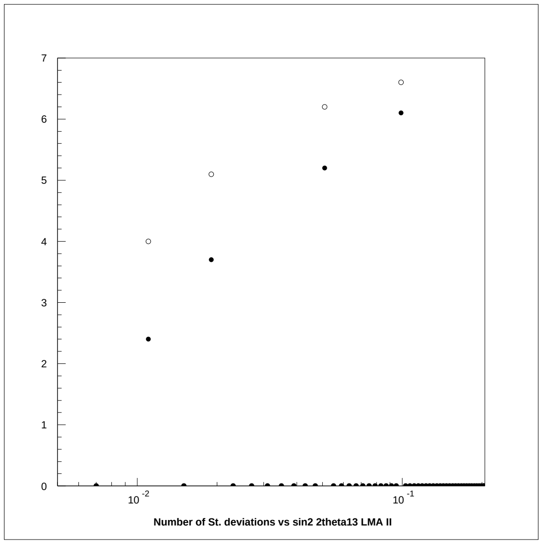


- At maximum of oscillation.
- Maximum CP violation.
- Two values of Δm^2_{12}.
- Run 1.5 years with Neutrino's
  and 4.5 years with Anti-neutrinos.
  To compensate for
  - the smaller cross-sections (factor of 2).
  - and the different π^+ , π^- production rates (factor of 1.5).

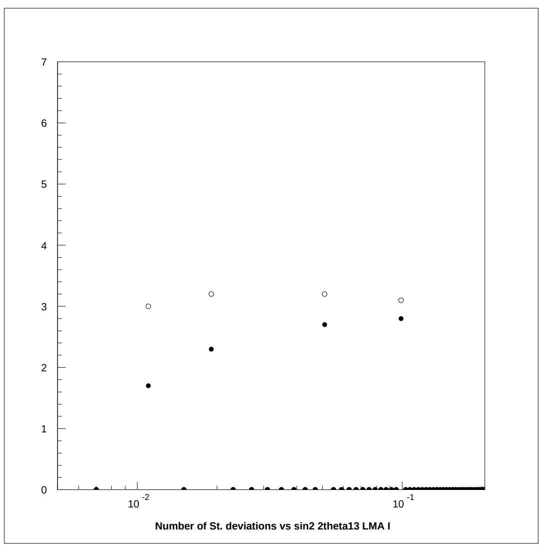
CP violation Possibilities

With the efficiencies and backgrounds of the $0.3\ X_0$ set up.
Calculate the number of standard deviations
on the DIFFERENCE
between the Neutrino and Antineutrino Rates.
Open circles: no background.
Closed circles: background included.

$$\Delta m^2_{12} \ = \ 1.5 \times 10^{-4}\ \mathrm{eV}^2.$$



$$\Delta m^2_{12} \ = \ 7.0 \times 10^{-5}\ \mathrm{eV}^2.$$



ENCOURAGING !

Work List

- Improve ν_μ background rejection.
  - Better tracking.
  - Use of Multi-Track information.
  - Better Likelihoods.
- Any way to reduce ν_e BEAM background ?
- Estimate background from ν_τ.
- Use different samples to define PDF's and estimate background.

CONCLUSIONS

- F The background level is MANAGEABLE.
- F There are schemes to estimate it.
- F The SIGNAL efficiency has improved from 29% in the LOI to 42%.
- F A thicker absorber is possible and reduces the FOM by a modest 16%.
- F Keeping X,Y planes together or separating them makes NO DIFFERENCE for a GIVEN number of detector planes.
- F If Nature is kind, a first look at CP violation could be possible.